A STUDY ON THE SLAGGING BEHAVIOR OF COAL ASH IN GASIFICATION/COMBUSTION ENVIRONMENT USING DTF

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ABSTRACT

The purpose of this study is to determine ash slagging behavior for the optimun ash removal in actual coal gasifier as well as combustor. DTF (drop tube furnace) was utilized for entire experiment to simulate real time and temperature history of coal particle. Pulverized particles of three different coal samples (Alaska, Cypurus and Datong) were injected into DTF with different experimental conditions. The slag samples deposited at the top of sample collector by the particle action of impacting and agglomerating. The formation shape of each deposited slag is related with physical properties of original ash such as ash fusion temperature, viscosity and surface tension. Phase diagram of main components of ash, i.e., SiO_2-CaO-Al_2O_3 system are analyzed to determine ash fusion behavior with different composition of the system. Shape of slag formation represents different behavior with gasification and combustion environment and also is effected by chemical composition of coal ash.

1. INTRODUCTION

Among the second-generation coal-fired power systems, IGCC (integrated gasification combined cycle) is characterized by highly efficient and environmentally sustainable technology. Since most of organic impurities of coal are converted into gas phase in gasification S- and N-containing gases can be easily separated from the product gas comparing to p.c. combustion technology. Moreover, CO_2 emission is reduced in IGCC technology because of its high electricity efficiency. Inorganic impurities of coal are also converted into slag in slagging-type coal gasifier. The volume of coal slag is reduced to 1/2~1/3 and the heavy metal compounds in coal ash is vitrified to non-leaching glass form.

In this experimental investigation, DTF is utilized to determine the characteristics and formation phenomena of ash slag generated with different coal samples. The result is analyzed for the relationship with chemical composition, ash fusion temperature and fluidity properties of coal ash. With above information, actual behavior of coal ash inside gasifier/combustor can be predicted so that optimum-operating condition for smooth slagging can be suggested.

2. EXPERIMENT

Characteristics of slag produced in slagging-type gasifier play a major factor in the continuous operation of actual gasifier. Flow properties of slag usually depend on viscosity and melting temperature, which were varied with inorganic constituents of coal ash. Ashes of three coal samples are analyzed with ICP-AAS for the inorganic constituents and the results are shown in Table 1. Generally speaking, reducing agents such as Fe_2O_3, CaO and Na_2O behave a role in reducing viscosity and melting temperature. On the other hand, oxidizing agents such as SiO and Al_2O_3 will increase viscosity and melting temperature.

Table 1. Chemical composition of coal ash samples

Composition(%) / Sample Coals	SiO_2	CaO	Al_2O_3	Fe_2O_3	TiO_2	Na_2O	K_2O	MgO
Datong	54.12	8.08	15.73	13.15	0.83	1.15	0.77	2.18
Alaska	44.83	20.20	19.30	7.01	1.11	0.70	1.40	3.90
Cypurus	51.60	11.37	19.30	5.73	0.84	2.71	0.83	2.11

Gas flow in the DTF reactor was arranged to laminar flow for the exact determination of reactivity and residence time of coal particles. The schematic diagram of DTF was shown in Fig. 1.

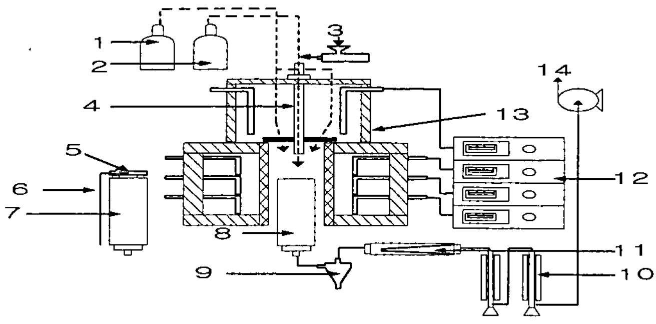


Fig. 1. Schematic diagram of Drop Tube Furnace (1: secondary gas line, 2: primary gas line, 3: coal feeder, 4: injector probe, 5: deposit disk, 6: R-type thermocouple, 7: deposit probe, 8: ash probe, 9: cyclone, 10: condenser, 11: ceramic filter, 12: PID controller, 13: furnace, 14: vent)

Coal feeding rate was fixed at 0.3g/min for entire experiment. In the combustion experiment, air were used for both primary and secondary carrier gas with the oxygen/coal weight ratio of 1.5. However, in the gasification experiment, primary gas was oxygen and secondary gas nitrogen with oxygen/coal ratio of 0.72, which is selected for maximum CO concentration in the product gas. While feeding coal particles at the top of the DTF and flowing carrier gases, reacted coal particles are collected at the top of deposit probe. Solid sample collector was installed inside deposit probe, which was made of metal substrate. Temperature was changed from 500℃to 600℃ for the simulation of heat transfer surface. To investigate the reaction between coal ash and alumina refractory, solid sample collector was also made of alumina refractory that was installed at 1500℃ in the deposit probe. Deposited ash samples was analyzed with photography for the shape of slag formation.

Ash fusion temperature was measured by standard ASTM method by using Ash Fusion Determinator (LECO model AF 600). Difference in FT and IDT, i.e. $\triangle$T is a factor which shows strength of ash deposit. Generally, if $\triangle$T is small, deposit thickness on reactor surface is thin and adhesive so that removal of ash deposit is very difficult. Table 2 shows fusion temperatures of each coal samples investigated in this study.

Table 2. Fusion Temperature of coal ash samples using ASTM method

Sample Coals	IDT(℃)	ST(℃)	HT(℃)	FT(℃)
Datong	1296	1304	1328	1359
Alaska	1205	1244	1263	1299
Cypurus	1249	1276	1301	1359

3. RESULTS AND DICUSSION

Liquid phase of coal slag behaves Newtonian fluid when flowing. When liquid phase is cooled, coal slag is transformed into pseudo-plastic solid state before solidification. Separation of solid state is dependent on composition of slag and transition temperature between liquid phase and solid phase, which is called critical viscosity temperature (T_{CV}). T_{CV} has same meaning of slag removal temperature which is ASTM fusion temperature with maximum viscosity for smooth slag removal. Slag removal temperature was identified as temperature with viscosity of 250 poise (T_{250}) so that choice of suitable coal for slagging operation is mainly decided by the value of T_{250}. A value of T_{250} was decreased by increasing the amount of reducing agents and by decreasing the amount of oxidizing agents in coal ash. When viscosity of perfect liquid phase is determined, critical viscosity temperature (T_{CV}) can be represented as crystallization temperature. Therefore T_{CV} and T_{250} have below relationship: $T_{CV} > T_{250}$, Slag removal temperature = T_{250}, $T_{CV} < T_{250}$, Slag removal temperature = T_{CV}.

Variation of slag viscosity with different composition was calculated by Urbain equation that is based on $CaO\text{-}Al_2O_3\text{-}SiO_2$ ternary phase diagram as in Frankel equation (1).

$$\ln\eta = AT\exp(B/T) \quad \text{-----(1)}$$

When calculating slag viscosity for low rank coal, equation (2) is used, where T is temperature, A and B are function of chemical composition on coal ash, η is viscosity in poise and $\triangle$ is silica percentage in slag.

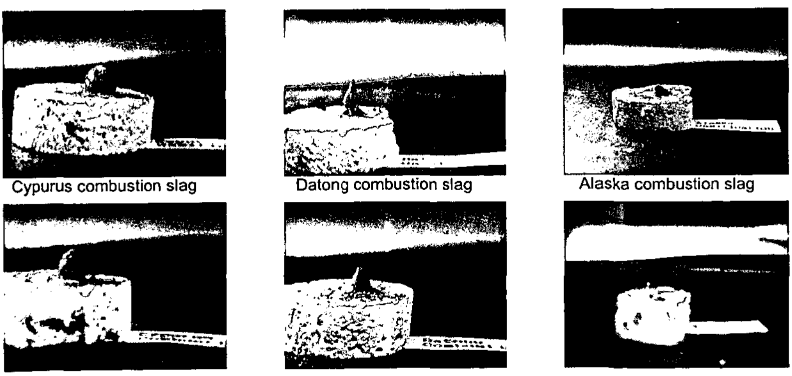
$$\ln\eta = \ln A + \ln T + 10^3(B/T) - \triangle \quad \text{-----(2)}$$

When using this equation, proper classification of silica quantity is very important which is largely dependent on the B values. Calculated data of viscosity at the temperature of T_{CV} for each coal samples are illustrated in Table 3.

Table 3. T_{CV} and viscosity of ash sample

Sample Coals	Viscosity (poise)	Tcv (℃)
Datong	348.18	1421
Alaska	364.92	1356
Cypurus	560.71	1394

The shape of slag samples with different experimental condition is illustrated in Fig. 2. Each formed slag shows slightly different shape with the variation of coal types and reaction atmosphere. Cypurus slag was not great difference between combustion and gasification condition, but shape of gasification slag more spherical shape than combustion condition. Datong slag shaped trigonal pyramid form and melting is started at the top of the deposit. Alaska slag shows flat melting shape because of its low melting characteristics. The variation of slag shape with different coal samples can be explained with the data of ash fusion temperature, surface tension and viscosity of slag with different slag composition. Also reactivity with refractory alumina substrate of solid sample collector affects shape of slag.



Cypurus combustion slag | Datong combustion slag | Alaska combustion slag

Cypurus gasfication slag | Datong gasfication slag | Alaska gasfication slag

Figure. 2 Shape of ash slag with gasfication/combustion condition and coal types

Coal samples in this study are classified into Alaska and Cypurus coal, which mainly consist of $SiO_2\text{-}CaO\text{-}Al_2O_3$ phase and Datong coal, which mainly consist of $CaO\text{-}SiO_2\text{-}Al_2O_3\text{-}Fe_2O_3$ phase. Mole fractions of Al_2O_3 and Fe_2O_3 in Alaska and Cypurus coals are constant but SiO_2/CaO ratio in ash components was varied from 2.07 in Alaska to 3.51 in Cypurus. For the slag samples mainly composed of $SiO_2\text{-}CaO\text{-}Al_2O_3$, viscosity is increased with increseing quantity of SiO_2 in slag.

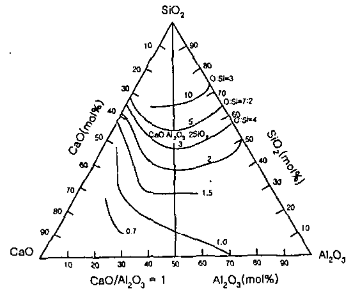


Figure 3. CaO-SiO_2-Al_2O_3 ternary diagram for coal ash samples

As shown in Fig. 3, however, Datong slag, composed of high quantity of SiO_2 and low CaO, would expected low fusion temperature and low slag viscosity. The main reason of such finding is because the reaction between high quantity of Fe_2O_3 and SiO_2 formed Fayalite(Fe_2SiO_4) which has low fusion temperature. Such finding is probably based on the fact that increasing quantity of Fe_2O_3 destroyed network structure of SiO_2.

Shape of slag formation with different gasification/combustion condition was effected by chemical composition of coal ash.

However,.shape of slag drop was mainly determined by surface tension value, which is subjected to wetting angle. Wetting angle between alumina refractory substrate and melting slag was represented by Young's relation as in equation (3), where O is wetting angle, r_{sv}, $r_{sl}$and r_{lv} are surface tension of solid-vapor, solid-liquid and liquid-vapor.

$$\text{Cos O} = (r_{sl} - r_{sv})/r_{lv} \quad (3)$$

If surface tensions of solid-vapor and solid-liquid are constant, surface tension of liquid-vapor phase behave major factor in the formation of slag drop. In other words decreasing surface tension of melting slag increase wetting angle. As a result, non-wetting surface was formed so that formed slag is not penetrated into porous alumina substrate.

4. CONCLUSION

To determine optimum operation condition of ash slagging in coal gasifier/combustor, DTF is utilized, which can simulate time and temperature history of coal particle. Slagging behavior of coal ash samples was also investigated with empirical equations and the results showed that slagging behaviors of subbituminous Alaska and Datong coals were much better than Cypurus. Separation of solid state dependant on composition of slag and transition temperature between liquid phase and solid phase by experiment data. Shape of slag formation with different on gasification/combustion condition was effected by chemical composition of coal ash. Shape of slag drop was determined by surface tension value, which is subject to wetting angle.

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